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SIMULATED DEEP SUBMARINE ESCAPE FROM 495 FEET OF SEA WATER

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Bureau of Medicine and Surgery, Navy Department
Research Work Unit MF12.524.006-9025B.34-2

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SUBMARINE MEDICAL RESEARCH LABORATORY
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Bureau of Medicine and Surgery, Navy Department
Research Work Unit M F12.524.006-9025B.34

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SUMMARY PAGE

THE PROBLEM

To conduct a series of simulated deep submarine escapes, utilizing the British Mark VII Submarine Escape Immersion Equipment (SEIE) in preparation for actual escapes to be made at sea.

FINDINGS

Successful simulated submarine escapes were made from 495 feet of seawater in the wet chamber at the Experimental Diving Unit by highly trained personnel under carefully controlled conditions with maximum safety procedures in force. It is considered that escape from this depth is entirely feasible employing the British Mark VII SEIE with current techniques of buoyant, free-breathing ascent. The above escapes were performed safely without decompression stops or recompression. The possible problems of CO_2 poisoning, O_2 poisoning, N_2 narcosis, decompression sickness, heat of compression and speed of compression were not encountered.

APPLICATION

The information presented in this report should aid the Naval Submarine Medical Center in the conduct of future "at sea" escapes and permit development of an improved submarine escape system incorporating the desirable features of the British Mark VII SEIE. The findings reinforce similar work in the United Kingdom which suggested that deep individual submarine escape from the continental shelf and deeper depths is practical.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Research Unit M F12.524.006-9025B - Assessment of Factors Related to Submarine Habitability, Escape and Rescue. The present report is No. 34. The manuscript was approved for publication on 18 March 1970, and designated as Submarine Medical Research Report No. 617.

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ABSTRACT

A series of simulated deep submarine escapes were conducted utilizing the British Mark VII Submarine Escape Immersion Equipment (SEIE). Two escapee subjects were exposed in a stepwise fashion to 2, 4, 8 and 16 ATA and brought directly to the surface. A rapid compression/decompression method was used employing the wet chamber at the Experimental Diving Unit. The above escapes were performed safely without decompression stops or recompression. The possible problems of speed of compression, heat of compression, CO_2 poisoning, O_2 poisoning, nitrogen narcosis and decompression sickness were not encountered.

SIMULATED DEEP SUBMARINE ESCAPE FROM 495 FEET OF SEA WATER

INTRODUCTION

A requirement to develop submarine escape and survival equipment (EASE) has been established by the Chief of Naval Operations in SOR* 46-15R2.

The EASE portion of the total system development must provide a capability to accomplish reliable personnel escape and optimize survival possibilities from a submarine bottomed at continental shelf depths and beyond.

The major objective of the above task is to develop submarine escape and survival equipment which will provide breathing gas, buoyancy and exposure protection for submarine personnel escaping from continental shelf depths and which will afford 24 hours of survival under conditions which could vary from 90° F water with 85° F air, still air and calm sea to 29° F water with 10° F air, 30 knot wind speed and state 6 sea.

At the present time, USN Submariners have essentially no exposure protection following escape from a bottomed submarine. The Steinke Hood, the escape appliance currently employed by the Fleet, together with whatever the man can don before escape, is all the thermal protection that is available.

The British Navy has developed an escape suit affording reasonable exposure protection, when related to the factors of storage requirement, cost, simplicity of operation, and a capability for 600 foot ascent. This escape suit embodies the concepts of single-man escape versus the USN group escape approach. Elliott[1] describes this individual escape concept in detail together with the trials that were conducted by the British Navy. The escape suit utilized in his report was the British Mark VI Submarine Escape Immersion Suit shown in Figure 1. The main features of the associated single-man escape tower are described in Figure 2. McNutt[2] conducted a thermal evaluation of the Mark VI suit and concluded that in 50° F water, 62.6° F still air most men would survive from 12 to 24 hours. The British exposure work did not incorporate the more severe environmental conditions encountered by USN submarines. Hall[3] evaluated the Mark VII Submarine Escape Immersion Suit (SEIS), which is essentially the same as the Mark VI suit except for the location of a zipper closure, and found that the average submariner tested would probably survive in 44° F water, 32° F air, 20 knot wind, for 24 hours.

In 1962, the British began looking toward a deeper submarine escape capability. In that year, a series of sea trials were successfully completed in which twenty-five pairs of men made escapes from keel depths down to 270 feet[4]. The escape appliance (a buoyant ascent jacket) at that time was being compared with a new Siebe Gorman Hood (a free-breathing, hooded, buoyant ascent jacket). Laboratory work was

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*Specific Operational Requirement (C)

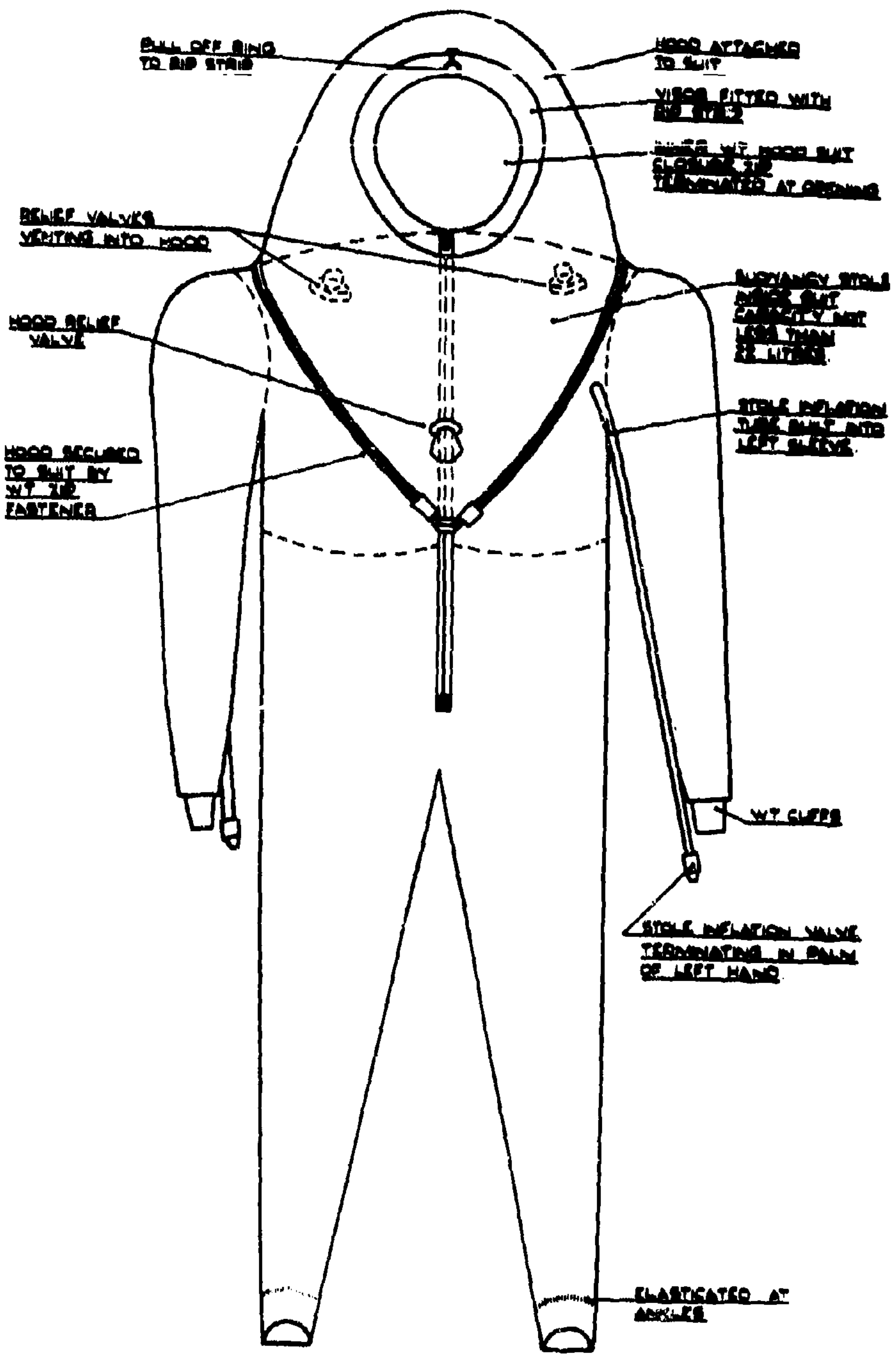

Fig. 1. A sketch of the escape immersion suit used in British trials

SUBMARINE ESCAPE TOWER

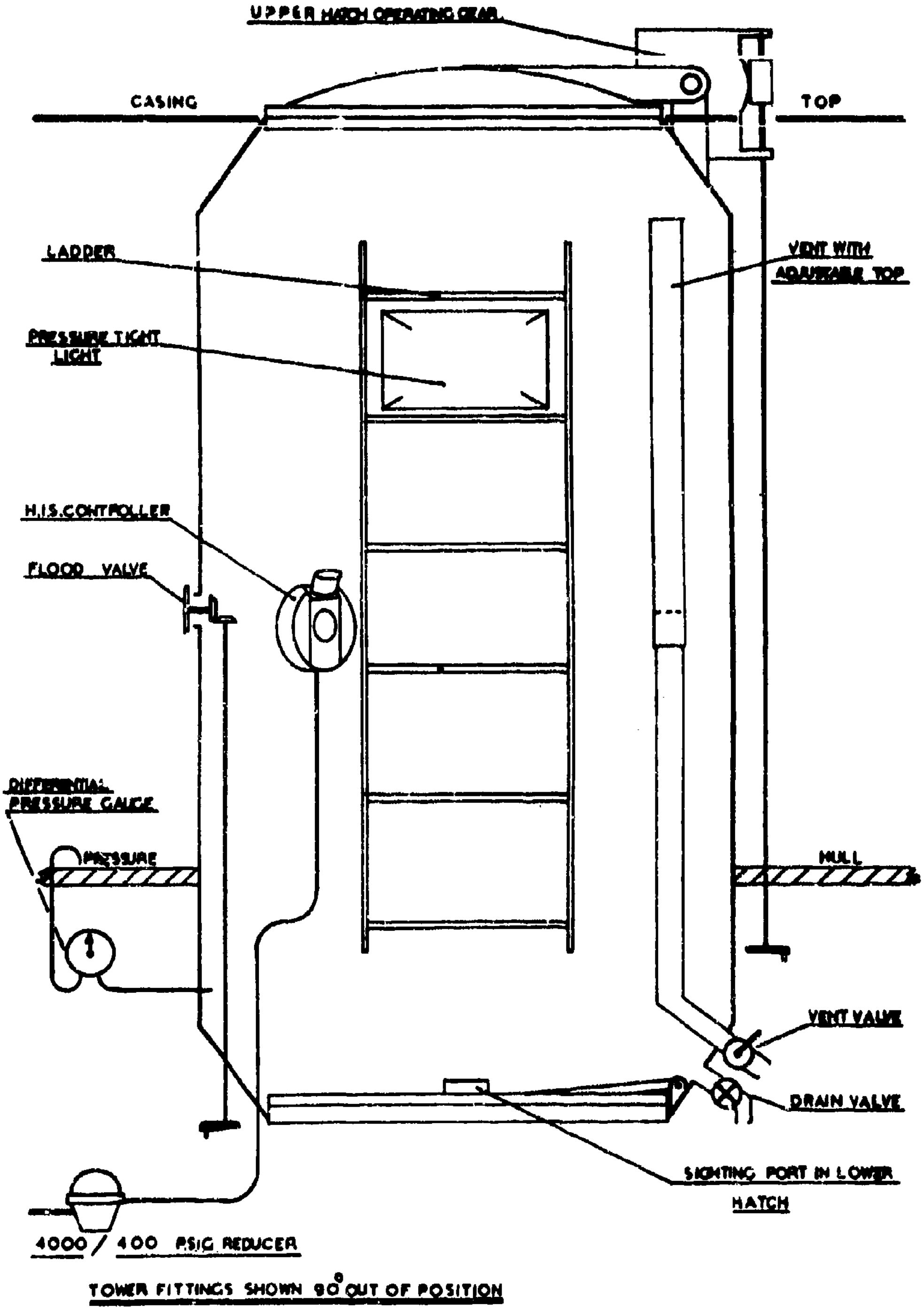

Fig. 2. A diagram illustrating the principal features of the single man escape tower

continued with goats employing rapid compression/decompression profiles[5]. Results of these studies encouraged human experiments in which about 200 no-decompression dives were performed by instructors from the Submarine Escape Training Tank, HMS Dolphin. Twenty seconds were taken for compression to depths down to 500 feet and 25 seconds were spent at pressure before ascending at 6 ft/sec. These men exhibited no symptoms of nitrogen narcosis or oxygen poisoning. One man whose age was over 40, had definite symptoms of decompression sickness after a 500 foot, 45 second no-decompression dive, but the remainder of the men had no symptoms, other than some skin itch. A hooded, buoyant immersion suit, Mark V, was fabricated and ascent work at HMS Dolphin suggested that a terminal velocity of 8 ft/sec. would be attained in the sea. Meanwhile a new system of very rapid water pressurization had been developed by the Director, General Ships. This system could provide rapid, controlled pressurization of the escape trunk needed to outrun the physiological limitations. The Mark VII SEIS was fabricated and was designed to be inflated at one psi above ambient pressure so as to provide a bubble of pure air for the man during his time spent in the trunk. There was no longer a need for the trunk to be filled with clean compressed air during pressurization. A hood inflation system (HIS) provides air to the stole portion of the suit and this air exhausts into the hood allowing the escapee to breathe freely. The stole was designed to be inflated automatically during compression. Figure 3 shows the inner workings of the HIS control valve. It is a reducing valve which operates on a simple servo-system. A separate "ultra-clean" supply of air stored in four 9.1 cu. ft. bottles at 4000 psi is reduced to 400 psi. This 400 psi air enters the HIS passing through the reducing valve and leaving at the pressure determined by the servo-system. The diaphragm portion of the reducing valve is balanced by the escape trunk's ambient pressure plus the spring pressure which is set at one psi. This air supply to the escapee remains positive to the ambient environment during the critical, rapid compression phase. Upon reaching the bottom or equalization of the trunk, the escapee could quickly make his escape.

This new system was employed in 1964. With the service of HMS Orpheus, 24 open sea escapes were made at depths down to 200 feet of sea water[6]. The simplicity of the operation and ease with which the escapees completed the escape evolution provided a strong argument for the system's being incorporated into future submarines as the primary method of escape.

In 1965 it was decided to conduct a series of deep open-sea escapes in the Mediterranean to verify recent laboratory findings and demonstrate a workable system approaching continental shelf depths. Eighty-seven successful escapes were made from keel depths down to 500 feet of sea water[7].

The British Mark VII SEIS can be donned in less than one minute. Just before the man enters the single man escape tower, the hood portion is

HOOD INFLATION SYSTEM CONTROLLER

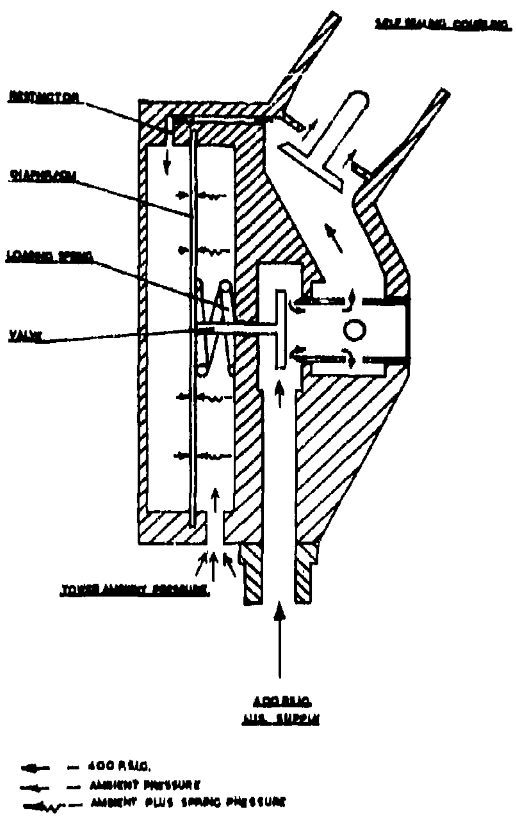

Fig. 3. The HIS control valve which supplies air at just above ambient pressure throughout the phases of flooding and rapid pressurization

zipped closed. After the escapee enters the escape tower, the trunk operator inserts the lower hatch and the escapee stands on it. The male part of the stole charging umbilical cord of his suit is inserted into the female charging portion of the Hood Inflation System (HIS). The HIS supplies the escapee with one psi over ambient pressure. This air is delivered to the stole which contains relief valves set a 0.5 psi. With one psi over ambient pressure being supplied to the stole, air is constantly exhausted into the hood and provides breathing gas to the escapee during the compression phase of the escape evolution. The lowest part of the hood contains an opening which acts as an exhaust valve for expanding hood air. The hood has a transparent face plate and a rip-strip on the side of the hood, for use in the event the zipper should jam on the surface.

The associated single-man escape trunk provides top hatch egress with nothing interfering with escapee during egress. The man is practically removed from this escape system in that all he must do is remember to plug into the HIS. Control of the trunk, including flooding at sea-level pressure and the hydraulic compression which follows is carried out by a trunk operator below. When equalization is accomplished, the over-head hatch is opened and the escapee having 70 lbs. positive buoyancy, ascends away from his HIS connection through the hatch opening to the surface at 9 ft/sec. With a bubble of cool, fresh air in the hood, free-breathing, buoyant-assisted ascent is accomplished.

Once on the surface the escapee unzips his hood, activates a CO_2 cartridge at his left hip, inflating the exposure portion of the suit, then dons and inflates a pair of gloves found in a pocket on his right leg.

After the escape, the upper hatch is secured, the trunk decompressed,

drained, and the next escapee readied. The entire escape evolution could be as short as three minutes.

In response to a request from the Director, Deep Submergence Systems Project Office, the Naval Submarine Medical Center undertook an investigation to study the human engineering factors involved with the submarine escape evolution. It was intended to determine for each of the various escape trunk configurations presently in use by the Submarine Forces of the U.S. Navy and alterations required for successful utilization of the British Mark VII SEIE to the rated depth of the escape trunk, or to the depth specified in paragraph 2 of SOR 46-15R2 (C). A specific objective of the study is to conduct a series of "live" escapes from a designated USN submarine at varying depths down to 500 feet of seawater (escape hatch depth).

In preparation for the proposed "at sea" escapes, it was necessary to conduct a series of deep simulated escapes utilizing the British Mark VII SEIE. It was expected that the series would enable an evaluation in a limited number of subjects of the effects of rapid air compression to 500 feet of sea water. Proper functioning of the Hood Inflation System (HIS) and the British Mark VII SEIS could also be verified.

Investigators from the Military Operations Branch of the Naval Submarine Medical Center, utilizing the facilities and personnel of the Experimental Diving Unit, Washington, D.C., were directed to conduct this experimentation.

Individual escape from a bottomed submarine can be divided into two phases. These are (1) the compression and egress phase, and (2) the decompression phase. A number of physiological and psychological factors effect these two areas of escape procedure.

During the compression and egress phase the following factors must be considered:

a. Decompression Sickness - Recent work indicates that this is the most severe limiting factor in deep submarine escape utilizing air. British experiments and USN calculations[8] indicate that if the bottom time does not exceed 30 seconds at 600 feet with the proper ascent rate, decompression sickness should not be experienced. Table I suggests maximum bottom times at various depths.

b. Nitrogen Narcosis - Because the breathing media is air, the effects of nitrogen at 600 feet are critical, based on the time of exposure. British[10] and U.S.[9] experimentation indicates that the length of time needed to effect the performance of the escape is well below nitrogen narcosis time limits.

c. CO_2 Toxicity - USN deep escapes[11] and more recent British escapes[4, 6, 7] indicate that with the rapid rates of compression and limited time at depth, alveolar CO_2 levels would remain relatively normal because of the (constant inhalation) dilution effects.

Table I. Time Limits for Escapes from Various Depths

Keel Depth	* Time (Min)
50 (PD)	100
100	25
200	3 3/4
300	2
375	1 1/2
425	1 1/4
475	1
525	1/2

* The bottom times shown have been derived from the USN Diving Manual, EDU studies, Workman calculations (8) and recent RN Experimentation (5, 7, 10, 16).

d. O_2 Toxicity - Breathing air at 600 feet is similar to inhaling 100% O_2 at close to five atmospheres absolute, but the length of exposure time should not allow time to develop symptoms. Other factors, such as exertion or elevated CO_2, could shorten the latent period of the symptoms to elevated O_2 tensions.

e. Compression Rate - All other previous physiological constraints can be avoided, if only a short exposure is allowed. To reduce the exposure, a rapid rate of compression must be employed. USN Trials[9,11] indicated such rapid rates are possible. British experimentation[5,10] and at sea escapes[4,6,7] indicate that pressurization at a geometric rate (constant volume change) may be the answer to rapid compression. Their compression profile indicated doubling of the pressure every four seconds (approximately 16-18 seconds to 600 feet). The possibility of ear and sinus barotrauma (squeeze) is present, but indications are that escapes could still be accomplished. Lung squeeze represents the real hazard and this rate of compression will produce it if the escapees do not inhale and exhale properly. Rate of compression will probably be the ultimate limiting factor in no-decompression submarine escapes. The heat produced by rapid compression appears to follow a polytropic rather than adiabatic curve. US Navy experience[11] and British trials[4,6,7] indicate that it does not represent the problem originally anticipated.

f. Psychological Effects - It is difficult to anticipate the mental attitudes of escapees after their submarine has been bottomed. Many events will effect their personal response. Simplicity of the system, confidence in their training and the possibility of survival and pick-up on the surface must be prominent in their minds[12].

During the decompression phase the following must be considered:

a. Air Embolism - Air trapping or holding the breath during ascent may result in air embolism in the central nervous system. U.S. Navy experience[9,11] and British work[5,7] indicate that ascents in excess of 540 ft./min. can be safely tolerated by the average submariner. With both the Steinke Hood and the Mark VII suit, the escapee breathes naturally from the air trapped in his hood.

b. Decompression Sickness - The decompression sickness described previously would manifest itself shortly after the escapee arrived on the surface. Any symptoms experienced would diminish the escapee's ability to survive on the surface.

METHODS AND MATERIALS USED

Two submariners were subjects for this project. The subject exposed first, was 33 years old and an instructor at the Submarine Escape Training Tank, Naval Submarine School (Groton, Conn.). He was the more experienced of the two men, having been involved for many years in submarine escape training; is a qualified HeO_2 diving officer; had been trained at HMS Dolphin in the British methods of escape; and had made open-sea escapes with this system down to 310 feet of sea water.

The second subject, age 28, was also stationed at the Escape Training Tank, at the Submarine Base, Groton, is an instructor in submarine escape procedures, a qualified underwater swimmer and experienced in deep positive pressure chamber work.

A complete medical evaluation was conducted by medical personnel at the Experimental Diving Unit and the National Naval Medical Center. The evaluation was detailed in the areas which were anticipated to be most influenced by the severe compression/decompression profile. The evaluation consisted of a medical history, physical examination, chest x-ray (PA and lateral), electrocardiogram, pulmonary function studies (including lung volumes, maximum breathing capacity, forced expiratory flow rate, peak flow rate, oxygen consumption and helium washout time), arterial blood gas determinations and ear, nose, and throat evaluation (including sinus x-rays and audiograms). Results of these studies were within normal limits.

A pre-dive physical examination revealed apprehension, which was expressed verbally and manifested as a mild tachycardia and increase in blood pressure.

The diving chamber (wet pot) portion of the positive pressure complex (Figure 4) at the Experimental Diving Unit, Washington, D.C. provided the environment necessary to simulate the submarine escape evolution. An off-the-shelf Hood Inflation System, consisting of a reducing valve working on a simple servo-system with charging chuck and associated piping, (Figure 5), was mounted on a ladder-stand simulating the positioning of this equipment in a submarine escape trunk. This whole unit was welded securely in position on a work bench in the wet environment (Figure 6).

Figure 7 shows a subject donning the SEIS. Figure 1 will provide comparative detail through a schematic with the actual suit.

Figure 8 illustrates the completely dressed escapee subject demonstrating the relative position to be maintained during the simulated escape runs. The left hand is forcibly holding the charging umbilical into the HIS charging chuck. This will supply compressed

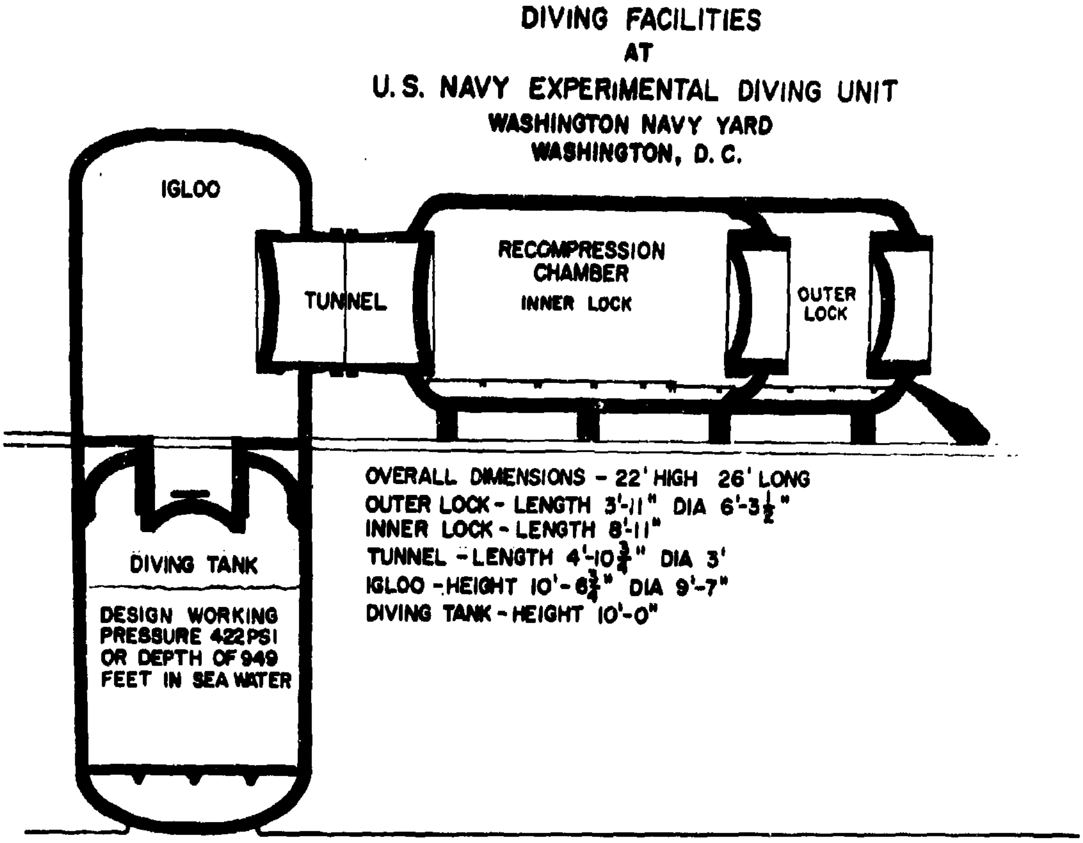

Fig. 4. Chamber complex at the Navy Experimental Diving Unit

air regulated at one psi over ambient pressure to the suit.

Pre-determined gas mixtures were supplied to the various compartments of the chamber complex. An outline of the chamber complex lineup and gas supply during the runs is found in Appendix A. The chamber complex received 2800 psi compressed air from large volume flasks. The Hood Inflation System (HIS) received 450 psi air reduced from the main supply 2800 psi

Fig. 5. The British Hood Inflation System (HIS)

air. Summitt[16] describes details of the chamber operation and control.

A doubling of the absolute pressure every four seconds would match the compression profile of the British Escape System. This would mean going from one to two atmospheres absolute in four seconds, two to four ata in four seconds, four to eight ata in four seconds, and eight to sixteen ata in four seconds. The pressure curve defined by this compression profile was duplicated where at all possible during the experimental runs. The decompression rate simulated that

Fig. 6. Hood Inflation System positioned in the Wet Pot

found "at sea" in the Mark VII SEIS of nine feet per/sec.

Heise 0-1200 foot, 660° cycle depth gauges were installed on the recompression chamber, igloo and wet pot. A pressure transducer/recorder system was installed to obtain accurate depth-time recordings for a permanent record. Malfunction of the transducer compromised these records. Stop watch times were obtained at 30, 100, 240 and 495 feet during compression and upon reaching the surface at the end of decompression.

Fig. 7. Subject donning the British Mark VII Submarine Escape Immersion Suit (SEIS)

Communications between the key points outside the chamber utilized an intercom system. Communications between the chamber operators and chamber occupants were obtained through the intercom system, visual signals, and direct visualization through the chamber ports. Communications with the escapee subject in the wet pot were maintained utilizing a hydrophone system, TV monitoring system, and a simple signal system (visual and auditory).

In order to attain the rapid compression rate necessary to duplicate the British System, the wet pot was flooded to within eight inches of the overhead hatch. The remaining volume of air could be rapidly pressurized. Water temperature averaged 68-70° F.

A series of unmanned runs was conducted to gain experience in reproducing the appropriate compression/decompression profiles. The HIS and a number of suits were exposed during this initial experimentation.

After an unmanned run, one subject at a time donned the British Mark VII SEIS. The subject was briefed, the appliance was inspected, and the escapee was lowered by stage down into the wet pot. With the assistance of a scuba diver, the subject was held down by a webbed belt and up by a quick-release strap. If properly positioned, the escapee was completely underwater, the webbed belt overcoming his buoyancy and the quick-release strap protecting him against sinking if he somehow lost his buoyancy. The scuba man retreated to the igloo overhead and the hatch was secured. Each simulated

Fig. 8. Escapee subject demonstrating the relative position to be maintained during the simulated escape runs

submarine escape followed the same procedure and is described in Appendix B.

The two subjects were exposed to the series of compression/decompression profiles shown in Table II.

Personnel assignments remained constant throughout the simulated submarine escape studies. A course of action to cover any potential hazard was outlined. The safety precautions, casualty procedures, and medical preparations are outlined in detail in Appendices C and D.

Table II. Simulated Submarine Escapes to be Completed by Subjects

Escape Run Depth (FSW)	Elapsed Time (Seconds) To Reach				Elapsed Time (Seconds) To -	
	30 Feet	100 Feet	240 Feet	495 Feet	Leaving Bottom	Reaching Surface
33	8				30	34
33	4				30	34
100	8	16			30	41
100	4	8			30	41
240	4	8	12		30	56
495	4	8	12	16	30	85

An official diving log was maintained throughout the series of dives. It contains a chronological record of the dive procedure and significant events incident thereto. A continuous video tape recording of the subject as seen through the TV monitoring system was obtained on all experimental runs. Photographic documentation of every major point in the procedural sequence, pre-dive and post-dive was obtained.

RESULTS

Tables III and IV show the six simulated submarine escapes each subject completed. Slow compression rates were employed in three of the six escapes in each subject. An attempt was made to double the pressure every four seconds in the remaining three experimental dives. Unfortunately, after 240 feet the ability to maintain the proper pressurization curve became impossible, but the total time to reach the bottom was fairly well maintained.

The average ascent rate for the practice runs was 5.6 feet per second and for the experimental runs was 8.65 feet per second. Two of the 33 foot runs were omitted from this calculation because ascent was interrupted to practice emergency procedures. Correction was made for the thermal cooling effect where applicable.

One additional factor is that the depth readings were taken from the bottom of the wet pot and indicated eight feet of sea water when the chamber was on the surface. To plot a curve representing the true change in pressure versus time, one would need to subtract eight feet from all the depth figures in Tables III and IV.

On the 33 foot and 100 foot runs, air was added as necessary during the bottom time to maintain depth; however, on the 240 foot and 495 foot runs, this was not done and thermal cooling resulted in a 10-25 foot decrease in depth before ascent.

Elapsed time to 33 feet, 100 feet, 240 feet, 495 feet and time of leaving the bottom were recorded to the nearest tenth of a second. Elapsed time to reaching the surface was rounded to the nearest one-half second.

Each subject received a medical examination and was thoroughly debriefed immediately after each dive. The physical examinations showed results which were all within normal limits. Specifically, there was no clinical evidence of O_2 toxicity, CO_2 intoxication, nitrogen narcosis, air embolism, decompression sickness or barotrauma to the lungs, ears or sinuses.

Both subjects commented on the heat of compression experienced on the 240 foot and the 495 foot runs, though neither thought it was significant enough to be of concern. While the temperature inside the hood was not measured, the subjects estimated it to be between 110°-120° F on the 495 foot run.

One subject experienced mild euphoria after reaching the bottom on the 495 foot run. This sensation continued throughout most of the ascent. The other noticed some disorientation on the bottom during the 495 foot run. This was manifested as a movement or

Table III. Simulated Submarine Escapes Completed by First Subject

Escape Run	Elapsed Time (Seconds) To Reach				Elapsed Time (Seconds) To -	
Depth (FSW)	30 Feet	100 Feet	240 Feet	495 Feet	Leaving Bottom	Reaching Surface
33	7.9				30	37
33 **	3.9				30	172
100	--	16.0			30	48
100	3.2	7.4			30	41.5
240	3.4	7.4	11.8		30	58
495	3.2	7.0	10.6	21.2	30	85

** Dives in which the ascent was interrupted to practice emergency procedures.

Table IV. Simulated Submarine Escapes Completed by Second Subject

Escape Run Depth (FSW)	Elapsed Time (Seconds) To Reach				Elapsed Time (Seconds) To -	
	30 Feet	100 Feet	240 Feet	495 Feet	Leaving Bottom	Reaching Surface
33	7.8				35	40
33 **	3.9				30	184
100	—	17.0			30	48
100	3.4	8.0			30	41
240	3.8	7.6	12.0		30	56
495	3.2	6.3	10.6	21.0	30	85

** Dives in which the ascent was interrupted to practice emergency procedures.

rotation of the underwater light directly across the chamber from him. This sensation disappeared when he focused his vision to a near point inside the escape hood.

The subjects remained at the Experimental Diving Unit for a minimum of two hours after each dive. In addition, they were instructed to have someone with them at all times during the twelve hours immediately following each exposure. At no time did either of the subjects experience symptoms indicative of air embolism, decompression sickness or barotrauma to the lungs, ears or sinuses.

DISCUSSION

The primary purpose of this study was to conduct a series of deep simulated submarine escapes utilizing the British Mark VII Submarine Escape Immersion Equipment in preparation for actual escapes to be made at sea.

British work[1,4,5,6,7,10] has shown that safe escapes can be made almost routinely using a rapid compression, single-man technique, from 500 feet of sea water. Recent work suggests that this escape system will be practical beyond continental shelf depths. However, risk to the individual escapee would undoubtably be significantly higher.

Animal experimentation to define the depth at which the mortality and/or morbidity will become unacceptably high are being conducted in England at this time. Deeper human experimentation under laboratory conditions is being planned. Open-sea escapes are also being considered in the near future at depths in excess of previous "at sea" trials.

No major difficulties were experienced in this series of simulated escapes. As previously discussed there were some indications of thermal change by the subjects, but the heat of compression remained well within an acceptable limit for human respiration and other necessary functions. Personal experience by the authors in recent "at sea" participation with the British utilizing this escape system showed that heat of compression is not a problem to the escapee. This is probably due to the magnitude of heat transfer to the sea water flooding the escape trunk. Interestingly enough, in previous British at sea escape trials a number of escape subjects accidently touched the metal zipper portion of the hood and noticed they were quite hot. Other sensations experienced by the subjects did not degrade their performance or result in detectable after effects.

The last US Navy at sea escape experience was conducted in 1961[9]. These trials were in support of introducing a new submarine escape appliance, the Steinke Hood. At that time a 300 foot escape capability was demonstrated. Recent work by the Naval Submarine Medical Center questions whether this is in fact a fleet-wide capability[17]. The configuration of USN submarine trunks present serious problems to the escapee in his bid to efficiently and effectively perform the escape evolution. The ability of a man wearing the present USN submarine

escape appliance with essentially no thermal protection to perform basic tasks during the exit phase of escape in cold water is questionable. His ability to survive on the surface remains very limited as studies of both the Royal Navy and US Navy have indicated. Recent work conducted by NSMC in conjunction with Air Crew Equipment Department of the Naval Air Development Center has shown that the Mark VII suit performed favorably in a variety of sea state, wave form, and wind conditions[18].

Incorporation of the following features of the British Submarine Escape System should significantly extend our present Fleet-wide submarine escape capability:

A. Escape appliance:

1. Exposure protection during escape and on the surface.

2. Automatic inflation during the compression phase.

3. Automatic release of air supply once on the bottom.

4. Auditory and visual means of detection on surface.

5. Ability to remain together on the surface.

B. Escape Trunk:

1. Hydraulic compression and conservation of high pressure air.

2. Negligible involvement by the escapee.

3. Top-Hatch egress.

4. Minimal fouling in trunk egress.

5. One or two man escape with minimal psychological interaction.

CONCLUSIONS

1. Successful simulated submarine escapes can be made from 495 feet of seawater, under carefully controlled conditions with a minimum of risk.

2. The methods and procedures utilized in this study would not require major revision for successful employment to depths in excess of 495 feet.

3. The possible problems of O_2 poisoning, CO_2 poisoning, N_2 narcosis, decompression sickness, heat of compression or speed of compression were not encountered in these dives.

4. These findings reinforce similar work in the UK which suggested that deep individual submarine escape from continental shelf depths and beyond is practical.

5. Development of an improved US Navy Submarine Escape System incorporating the desirable feature of the British Escape System is worthy of serious consideration.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the cooperation shown by the Commanding Officer and men of the Navy Experimental Diving Unit, Washington, D.C. who modified their facility to meet the needs of the experiment requested by the Naval Submarine Medical Center and performed in an outstanding manner.

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A special "well done" is given to the test subjects CWO E. D. BARNES, USN, and QMC W. W. HOELLER, USN, whose enthusiasm, trust and experience were instrumental in accomplishing this task.

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APPENDIX

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APPENDIX A - CHAMBER COMPLEX LINEUP AND GAS SUPPLY

I. Chamber Complex Lineup.

A. Recompression Chamber.

1. Lineup to compress on air and pure helium.

2. Setup mask manifold on 94%-6% HeO_2.

B. Igloo.

1. Lineup to compress on air and pure helium.

2. Mask manifold setup on 94-6% HeO2.

C. Wet Pot.

1. Lineup to compress on air.

2. Open circuit demand manifold setup on 94-6% HeO_2.

3. 400 p.s.i. air to the HIS (reduced from 3000 psi).

II. Atmosphere monitoring instruments: IR215 CO_2 analyzer and F-3 oxygen analyzer setup and calibrated to monitor chamber atmosphere, if required.

III. Emergency Gas; 94-6% HeO_2

Depth (FSW)	PO_2 (ATA)
60	.17
100	.24
150	.33
200	.42
250	.51
350	.70
450	.88
550	1.06
650	1.24
750	1.42

IV. Treatment Gases.

Depth (FSW)	Mixture	PO_2 (ATA)
60	100% O_2	2.8
100	60-40% HeO_2	1.6
150	60-40% HeO_2	2.2
200	60-40% HeO_2	2.8
250	80-20% HeO_2	1.7
350	80-20% HeO_2	2.3
450	80-20% HeO_2	2.9
550	90-10% HeO_2	1.8
650	90-10% HeO_2	2.1
750	90-10% HeO_2	2.4

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APPENDIX B

SEQUENTIAL DESCRIPTION OF A SIMULATED SUBMARINE ESCAPE DIVE

1. All Equipment/supplies verified ready.

2. Chamber condition and lineup verified ready.

3. Subjects - P.E.'s complete - verified ready.

4. Flood wetpot to desired level.

5. Subject suited and secured in position - check operation of HIS.

6. Close wet pot hatch -

   a. Medical Officer, Corpsman, one Tender and Medical Equipment topside in igloo.

   b. Diving Officer, Master Diver, Medical Officer on station at wet pot.

7. Signal from subject when ready to compress.

8. Continuous signal from subject indicating OK.

9. Countdown to begin compression.

10. Compress wet pot at predetermined rate.

11. Signal subject when on bottom - subject disconnects HIS.

12. Bottom time 30 seconds (includes descent and actual bottom time).

13. Ascend at rate 540 FPM (9FPS).

14. Signal subject when on surface.

15. Open wet pot hatch and move subject into igloo.

16. P.E. just outside igloo - subject remain standing in this area for 10 minutes.

17. Complete P.E. in the conference room.

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APPENDIX C - SAFETY PRECAUTIONS AND CASUALTY PROCEDURES

I. General Safety Precautions.

A. Equipment and Supplies:

1. Required medical supplies located in the igloo ready for immediate use.

2. Thorough check of all equipment and systems for proper operation.

3. Chamber gas supply lined up for immediate use and the required high oxygen treatment mixtures available in cylinders.

B. Personnel:

1. A Medical Officer, Corpsmen, and one Tender located in the igloo ready for immediate compression.

2. Diving Officer, Medical Officer, Master Diver, and Chamber Operator located at the wet pot control station.

3. Chamber operators located at the chamber and igloo control stations ready for immediate compression, if required.

C. Communications:

1. Hydrophone and intercom systems available for use when practical.

2. Television monitor provides continuous view of the subject and chamber complex.

3. Simple signal system for rapid routine or emergency communications.

II. Casualty Procedures.

A. During the compression and bottom time phases:

1. Anticipated possible problems: Ear squeeze (middle and external), sinus squeeze, lung squeeze, and nitrogen narcosis.

2. The emergency (abort) procedure will be initiated by the Diving Officer if:

a. The subject fails to give a continuous OK signal.

b. The subject shifts position so that he cannot be adequately visualized at all times.

c. The subject gives a HOLD or STOP signal.

d. Equipment malfunction is suspected, i.e. failure of the HIS, etc.

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e. Any condition exists that, in the judgement of the Diving Officer, constitutes a breech of safety.

3. Procedure

a. STOP DESCENT.

b. ASCEND 50 Feet (thermal cooling will probably accomplish this quickly). (Use exhaust if required.)

c. HOLD THE DEPTH obtained in (b) above for a total elapsed time of 30 seconds (includes descent and time at depth).

d. Ascend to the surface at 240-300 FPM (4-5 FPS).

e. Signal to the subject when on the surface.

f. Open wet pot hatch and move subject to the igloo.

g. Medical team assume responsibility for diagnosis and treatment of the casualty.

h. All hands remain at assigned stations until relieved by the Diving Officer.

B. <u>During Decompression Phase:</u>

1. Anticipated possible problems: Nitrogen narcosis, air embolism, and decompression sickness.

2. Emergency procedures will be initiated by the Diving Officer if:

a. The subject fails to give a continuous OK signal.

b. The subject gives a HOLD or STOP signal.

c. Diving Officer considers such action as being necessary.

d. The subject is obviously unconscious or in difficulty.

3. Procedure.

a. <u>Casualty occurring deeper than 300 feet:</u>

1) SLOW ASCENT to 240-300 FPM (4-5 FPS).

2) STOP ASCENT at 300 feet and hold that depth.

3) Compress the igloo on air (with the medical team)

to 300 feet to meet the wet pot - medical team go on masks breathing 94-6% HeO_2 at 100 feet.

4) Open hatch to wet pot and move subject to the igloo. If desired, place subject on mask breathing the 94-6% HeO_2 - Initiate medical treatment.

5) Compress the chamber to 30 feet on air and then to the same depth as the igloo on pure helium (oxygen 0.40 ATA).

6) Transfer the medical team, subject and medical equipment to the recompression chamber. The igloo can then be brought to the surface and recompressed on helium.

7) Initiate recompression treatment, if required. Recompression can be accomplished in the igloo as long as all personnel are breathing HeO_2 by mask.

b. Casualty occurring between 300 and 170 feet:

1) STOP ASCENT immediately and hold that depth.

2) Compress the igloo on air (with the medical team) to the same depth as the wet pot. Medical team go on masks breathing 94-6% HeO_2 at 100 feet.

3) Open hatch to wet pot and move subject to the igloo. If desired, place subject on mask breathing 94-6% HeO_2. Initiate medical treatment.

4) Compress the chamber to 30 feet on air and then to the same depth as the igloo on pure helium (oxygen 0.40 ATA).

5) Transfer the medical team, subject and medical equipment to

the recompression chamber. The igloo can then be brought to the surface and recompressed on helium.

6) Initiate recompression treatment, if required. Recompression can be accomplished in the igloo as long as all personnel are breathing HeO_2 by mask.

c. Casualty occurring between 170 and 60 feet:

1) STOP ASCENT immediately and hold that depth.

2) Compress the igloo on air (with the medical team) to the same depth as the wet pot.

3) Open the hatch to wet pot and move subject to the igloo. Initiate medical treatment.

4) Compress the chamber to 30 feet on air and then to the same depth as the igloo on pure helium (oxygen 0.40 ATA).

5) Transfer the medical team, subject and medical equipment to the recompression chamber. The igloo can then be brought to the surface and recompressed on helium.

6) Initiate recompression treatment, if required. Recompression can be accomplished in the igloo on air as deep as 170 feet without requiring HeO_2 breathing by mask. Compression to deeper depths on air require that the medical team breathe HeO_2 by mask. The subject can also be placed on HeO_2 by mask, if desired; but this is not an absolute requirement until depth exceeds 300 feet.

d. Casualty occurring between 60 feet and the surface:

1) STOP ASCENT and hold that depth.

2) Compress the igloo on air (with the medical team) to the same depth as the wet pot.

3) Open the hatch to wet pot and move subject to the igloo. Initiate medical treatment.

4) Initiate recompression treatment, if required, by recompressing the igloo with pure helium. The chamber can be taken to depth at a later time as needed.

C. Casualty occurring after reaching the surface:

1. Anticipated possible problems: Air embolism and decompression sickness.

2. Treatment procedure.

a. The Short Oxygen Tables (5, 5A, 6, 6A) will probably be adequate for treatment of these casualties. Since there may be difficulty distinguishing between decompression sickness and air embolism under these circumstances, Tables 5A and 6A will be used when uncertainty is present.

b. For the purpose of this experiment, Tables 5A and 6A will be modified to allow for the possible need for recompression treatment deeper than 165 feet, i.e. the chamber will be compressed to 30 feet on air and then to 165 feet on pure helium. Should a deeper treatment depth be required, travel to that depth will be made on pure helium.

D. Casualty requiring treatment deeper than 170 feet (without regard to when it occurs in the dive sequence):

1. Chamber atmosphere will be a helium-oxygen mixture containing 0.38 - 0.40 ATA of oxygen. If initial compression is on air, steps will be taken as soon as possible to convert to the helium-oxygen environment. This will allow the medical team to work without the

inconvenience of masks or nitrogen narcosis.

2. As long as the chamber environment is AIR, a 94-6% helium-oxygen mixture will be available by mask. This mixture can safely be used from 100 to 750 feet.

3. HeO_2 mixtures will be available to deliver high oxygen levels by mask for intermittent treatment schedules. These mixtures have been selected to provide treatment mixes between the surface and 750 feet.

4. After treatment has been completed at depth, decompression will be accomplished using a modified form of the saturation dive abort schedules written for the saturation dives conducted at EDU (1966-68) and the 1000 foot saturation dive at Duke University. Abort schedules are available for depths to 1000 feet and bottom times up to 4 hours. Longer bottom times would probably obligate to a saturation dive type decompression profile.

APPENDIX D - MEDICAL SUPPLIES

I. Drugs (Intravenous)

1. Isuprei
2. Epinephrine
3. Nor-Epinephrine
4. Sodium Bicarbonate
5. Phenobarbital
6. Xylocaine (1%)
7. Calcium Gluconate
8. Decadron
9. Solu-Cortef
10. Mannitol
11. Atropine

II. Fluids (Intravenous)

1. D5W
2. D5/S
3. Rheomacrodex

III. Diagnostic and Theraputic Equipment

1. Thoracentesis tray with Klaggett needles
2. Tracheostomy tray
3. Suction bottles
4. 12 inch large intracaths
5. 24 inch large intracaths
6. EKG
7. Laryngoscope
8. Cuffed endotrachael tubes
9. Ambu bag
10. Oral-Nasal airway
11. Blood pressure cuff
12. Otoscope
13. Ophthalmoscope
14. Tuning forks
15. Reflex hammer
16. Stethoscope
17. Tracheal suction catheters
18. Nasogastric tube
19. Foley catheter (with bag)
20. Syringes and needles
21. Tape
22. 4 x 4 Gauze bandages
23. Bacitracin ointment
24. K-Y jelly
25. Tourniquets
26. #8 Sterile gloves
27. Alcohol sponges (covered).

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13. ABSTRACT

A series of deep simulated submarine escapes were conducted utilizing the British Mark VII Submarine Escape Immersion Equipment (SEIE). Two escapee subjects were exposed in a step-wise fashion to 2, 4, 8 and 16 ATA and brought directly to the surface. A rapid compression/decompression method was used employing the wet chamber at the Experimental Diving Unit. The above escapes were safely performed without decompression stops or recompression. The anticipated problems of speed of compression, heat of compression, CO_2 poisoning, O_2 poisoning, nitrogen narcosis and decompression sickness were not encountered.

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